EFFECTS OF FOREST MANAGEMENT PRACTICES ON MID-ATLANTIC STREAMS

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Abstract. Agricultural and urban land use activities have affected stream ecosystems throughout the mid-Atlantic region. However, over 60% of the mid-Atlantic region is forested. A study was conducted to investigate the effects of management practices on forested stream ecosystems throughout the mid-Atlantic region. The study consisted of two phases: Phase 1 was a literature synthesis of information available on the effects of forest management practices on stream hydrology, erosion and sedimentation, riparian habitat alteration, chemical addition, and change in biotic diversity in the mid-Atlantic region. In Phase 2, data from mid-Atlantic streams were analyzed to assess the effects of forest land use on stream quality at the regional scale. Typically, it is the larger order streams in which monitoring and assessment occurs—3rd order or higher streams. The impacts of forest management practices, particularly hydrologic modifications and riparian buffer zone alteration, occur predominantly in first and second order streams with cumulative impacts translating to higher order streams. Based on the literature review and mid-Atlantic Highland streams analysis, there are short-term (e.g., 2 to 5 years) effects of forest management practices on stream quality at local scales. However, signatures of cumulative effects from forest management practices are not apparent at regional scales in the Highlands. In general, forested land use is associated with good stream quality in the region compared with other land use practices.

1. Introduction: Forest Effects on Stream Quality

Over 60% of the mid-Atlantic region is in forest land cover, which supports a large timber industry. Of this forest land, about 28 million acres are actively managed for timber. In addition to providing timber, forests reduce soil erosion and sedimentation, remove atmospheric contaminants, produce oxygen, provide habitat for wildlife including native and neotropical birds, sustain streams and stream communities, and provide recreational and aesthetic experiences. In the mid-1990s, protocols were formulated for sustaining the world's forests. The Santiago Declaration for the Conservation and Sustainable Management of Temperate and Boreal Forests (Anonymous 1995) identified six themes necessary to sustain global forests. One of these themes was conservation of forested aquatic ecosystems. While proper forest management leads to sustainable ecosystems, poor forest management practices, particularly during timber harvesting and road construction, can significantly degrade not only the terrestrial ecosystem, but also the associated stream ecosystem.

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Local scale effects of forest management and timber harvesting practices on stream ecosystems have been studied and well documented in the literature (Bormann et al. 1974, Likens et al. 1970, 1977). However, forest management and timber harvesting practices have changed substantially over the past 20 years as additional best management practices have been identified and implemented. Over this same period, it has become apparent that forest management practices on relatively small areas can have large scale impacts in toto on the landscape (Forman and Gordon 1986, Forman and Mellinger 1998, Turner 1989). Because streams are a product of their watersheds (Hynes 1977), these larger scale impacts might also create large-scale effects on stream quality.

This paper reviews local scale effects of forest management practices on streams in the mid-Atlantic region over the past 20 years, develops a conceptual model of these effects, and analyzes information from a regional stream monitoring program to determine if forest management practices at the local scale can be detected at a regional scale.

2. Forest Management Practices and Stream Quality: Local Scale Effects

Forest management and harvesting practices can have multiple effects on stream quality including modified watershed hydrology and water balance, erosion and sedimentation, habitat alteration, chemical contamination, and altered stream biology (Binkley and Brown 1993, Dahlgren and Driscoll 1994, Dietterick and Lynch 1989, Likens et al. 1977, Wigley and Roberts 1994). These effects are not independent, but rather are linked and interactive (Figure 1). Addressing hydrologic modifications, for example, can also address erosion and sedimentation, habitat alteration, nutrient transport, and effects on stream biota.

A literature review was conducted to assess the local scale effects of forest management and harvesting practices on stream quality. Some of the cumulative effects of forest management practices on stream ecosystems are shown in Figure 2. For example, streamflow and peak stormflow discharges (Q = runoff) increase following timber harvesting due to loss or decreases in interception and evapotranspiration (ET), and increased soil moisture storage (Dietterick and Lynch 1989, Hibbert 1967, Hornbeck et al. 1978). The increases in streamflow are typically proportional to the intensity of harvesting, with clearcutting of entire stands causing maximum changes in watershed and stream hydrology (Patric 1978).

This increased runoff can result in greater sediment delivery to the streams along with increased discharge of soil nutrients, both macro and micronutrient export from the watershed (Figure 2). Fine sediment contributions to streams in forested watersheds have occurred due to poorly designed roads and ditches; cutbanks, slope failures, and debris flows; stream erosion and channel scour from increased peak flows; and diversion of streams at haul road crossings (NCASI

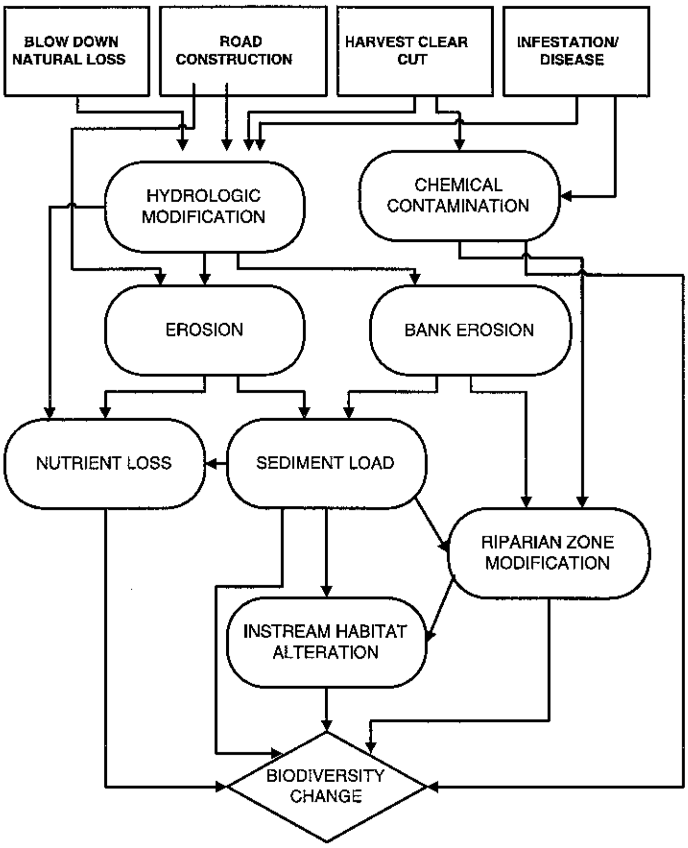

Figure 1. *Linked and interactive effects of forest management practices on stream quality.*

1994). Sediment production generated through storm flow from poorly designed logging roads is the most common cause of water quality degradation in forested watersheds (Binkley and Brown 1993, Corbett et al. 1978, Riekerk 1983).

Increased stream velocities, from increased discharge and peak flows, can result in increased channel scour, bank erosion, and bank slumping, affecting the physical habitat in the stream (Dietterick and Lynch 1989) (Figure 2).

Removing the streamside or riparian vegetation during harvesting can result in increased sediment and slash delivery to the stream, increased sediment accumulation in the streambed, increased stream temperatures and nutrient concentrations, and decreased stream quality (Binkley and Brown 1993, Norris 1993). Increased chemical contributions to streams during and following harvesting have been recorded for nutrients, particularly nitrogen, cations and anions (Ca, K, Na, Mg, SO_4, Cl), and herbicides or insecticides used to control weeds or insects following harvest (Corbett et al. 1978, Dahlgren and Driscoll 1994, Edwards et al. 1991, Norris et al. 1984).

Increased sediment accumulation and alteration of the physical habitat can affect the stream biological community. Increased slash during logging can significantly alter the transport of woody debris and leaf litter to the insect community, and the size distribution of organic matter (fine versus coarse) which can alter both the composition and abundance of species in the community (Stout et al. 1993) (Figure 2).

Greater solar insolation reaches the stream, particularly in smaller first and second order streams, because the overstory vegetation has been removed. This can contribute to increased primary productivity because of the concurrent increase in nutrient export from the watershed (Figure 2). Changes in the stream temperature can affect fish by influencing their metabolic rate, hatching, development, and migration patterns. Increased sediment accumulation in fish spawning gravel beds can reduce the diffusion of oxygen into the spawning beds and decrease the fecundity of stream fishes (Binkley and Brown 1993).

Forest management practices can have significant local scale effects on stream ecosystems. These effects, however, can be reduced through implementation of BMPs as part of forest management (Ice et al. 1997, NCASI 1994, Norris 1993).

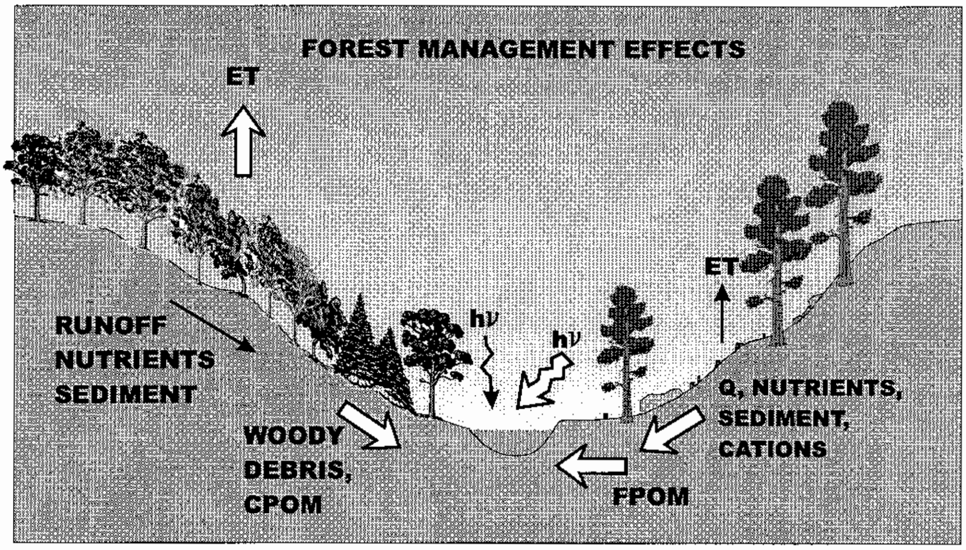

Figure 2. *Cumulative effects of forest management on a stream or watershed. Changes in arrow size reflect changes in the magnitude of the process before and after timber harvest. Elements include evapotranspiration (ET), solar insolation (hv), runoff (Q), coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), nutrients, sediments, cations and woody debris.*

3. Forest Management Practices and Stream Quality: Regional Effects

Local scale effects of forest management practices on stream quality can be detected, but is there a cumulative signature of these local scale effects at a regional scale? To answer this question, information on stream quality was obtained from the EMAP Mid-Atlantic Highlands stream monitoring program. About 360 stream reaches, selected as probability samples using the EMAP sample survey design, were sampled once during the 1993–1994 spring season. These stream reaches represent over 110,000 stream km in the Highlands on a 1:100,000 scale map. Most of the streams were located in Pennsylvania and West Virginia. In addition to stream measurements, general watershed characteristics (e.g., area, slope, land use/land cover, disturbance, etc.) for the watershed upstream of each sampled stream reach were determined by digitizing watershed areas and elevations from topographic maps. Land use/land cover was classified as urban, agriculture/range land, forest, water, wetlands and mines/quarries using remotely sensed imagery. Stream attributes were measured on riparian and instream habitat, chemistry, fish, benthos, periphyton, and stream metabolism in each sampled stream reach. All of the streams in the mid-Atlantic Highlands were first through third Strahler order streams (Strahler 1964) so very few streams were gaged. Increases in flow regime as a function of land use and forest management practices, therefore, could not be determined. The emphasis in this paper is on management practices that might be observed on a regional scale by analyzing habitat, chemistry, stream insects, and fish information.

Because the mid-Atlantic region has almost two-thirds of the area in forests, the proportion of forested watershed associated with different stream orders was investigated. Over 95% of the watershed area associated with first order streams was forested, with only about 2% of the watershed in agriculture and another 1% in other land use. About 80% of the watershed area associated with second order streams was forested with 20% of the watershed in agriculture. The proportion of the watershed in agriculture for third order streams was similar to second order streams, but the proportion of forested watershed area decreased to about 75%. While many fisheries management agencies emphasize the importance of third order and higher streams for sportfishing, first and second order streams are important in maintaining and sustaining these fisheries. In the mid-Atlantic Highlands, almost 75% of the first order stream miles contained fish and over 25% of the first order streams had gamefish. Over 90% of the second order stream miles had fish and two-thirds of all the second order stream miles had game fish. Over 90% of the third order stream miles had gamefish and less than 2% of third order streams had no fish. First and second order streams are important for sustaining fisheries within the Highlands so forest management practices, even in small watersheds with lower order streams, can have significant effects on a stream fishery.

An initial evaluation of the effect of forest land cover and associated management was conducted by partitioning the streams by stream order and by land use or

Table I

Land use/land cover associated with Highland stream watersheds, by stream order, and fisheries associated with these stream orders.

	Land Use (Median % of Watershed Areas)			% of Stream Miles with		
Stream Order	Forest	Agriculture	Other	No Fish	Fish	Gamefish
1	97	2	1	26	46	28
2	80	20	0	8	26	66
3	75	20	5	2	5	93

cover. As a rule of thumb, the stream signature from agriculture becomes dominant whenever the proportion of agriculture exceeds about 10% of the watershed area (Omernik 1977). Therefore, each of the stream orders was partitioned into two categories—those streams whose watersheds had at least 95% of the watershed area in forest land cover, and a second category of streams whose watersheds had less than 95% of the area in forest land cover. The watersheds classed as >95% forested had a median land cover of 99% forest regardless of stream order (Table II). The median percent land cover in the other watershed category was 62% forested for both first and third order streams and 70% forested for the second order streams. Agriculture was the other dominant land use in this watershed mixed land use category. Watershed areas were similar within stream order regardless of land use with the mixed land use watershed category having slightly larger median areas.

Soil erosion and sediment delivery to streams and increased sedimentation were local scale effects associated with logging and forest management practices in the watershed. Much of the erosion and runoff was because of poor road construction and an increase in road density during timber harvesting. To assess the potential regional effects of erosion, sediment delivery and sedimentation, road density, total suspended solids (TSS) concentration, and percent fines (clays and silts) in the stream bed were compared between the forested and mixed land use watersheds, by stream order (Table II). For all stream orders, the median road density was 2 to 3 times greater in mixed land use watersheds compared to forested watersheds. Median TSS concentrations also were two to three times greater in streams in mixed land use watersheds compared to forested watersheds (Table II). The percent fines in forested watersheds stream beds were 8 to 10 times lower than in stream beds associated with mixed land use watersheds regardless of stream order. In general, potential physical and habitat stressors on Highland streams were of lower magnitude in forested watersheds than in mixed land use watersheds.

Table II

Comparison of forested watershed (>95% forest cover) stream median characteristics with mixed land use watershed (<95% forest cover) stream median characteristics.

	% Forested		Watershed Area (km^2)		Road Density (m/ha)		TSS (mg/L)[1]		% Fines (% stream bed)	
Order	>95%	<95%	>95%	<95%	>95%	<95%	>95%	<95%	>95%	<95%
1	100	62	1.5	1.9	6.9	18	3.8	7.7	2	17
2	99	70	11.1	14.6	6.1	15.2	2.0	4.4	2	12
3	99	62	51.4	63.9	8.9	16.3	1.2	4.7	1	14
	Woody Debris (# pieces/100 m)		NO_3 (mg/L)[2]		TP (mg/L)[3]		EPT (# genera)[4]			
Order	>95%	<95%	>95%	<95%	>95%	<95%	>95%	<95%		
1	23	11	0.7	1.4	.008	0.022	12	11		
2	9	12	0.4	1.9	.006	0.018	13	11		
3	11	6	0.5	1.9	.006	0.016	16	10		

[1] Total suspended solids (TSS)
[2] Nitrate-nitrogen (NO_3)
[3] Total phosphorus (TP)
[4] *Ephemeroptera-Plecoptera-Trichoptera* (EPT) aquatic insect index

Woody debris, particularly in small first order streams, is important both as a food source and as habitat for aquatic organisms. The median number of pieces of woody debris was about twice as high in first and third order streams in forested watersheds compared to similar streams in mixed land use watersheds, but about 30% higher in second order streams in mixed land use watersheds (Table II). Median nutrient concentrations (nitrate-nitrogen [NO_3] and total phosphorus [TP]) were two to three times lower in streams with forested land use compared with mixed land use watersheds, regardless of stream order.

Benthic insects, particularly the number of species or genera in three insect orders, *Ephemeroptera, Plecoptera and Trichoptera* (EPT), are used as indicators of stream condition. Greater numbers of EPT genera are associated with better stream condition. The numbers of EPT genera were compared for streams in forested versus mixed land use watersheds. In general, the numbers of EPT genera in forested watershed streams were higher than in mixed land use watershed streams, but only in third order streams were the numbers of EPT genera significantly different in forested watersheds compared to mixed land use watersheds (Table II).

An attempt was made to partition the forested land use watersheds into those watersheds with visible signs of logging during sampling and those watersheds with no visible or apparent signs of logging (Table III). There were a limited number of sites ($n = 7$) with visible signs of logging. A comparison was made between median attribute values for first order streams in recently logged (< 2 years) versus previously logged (> 20 years) unharvested watersheds. Median road density was over twice as high in recently logged watersheds. Streams in these recently logged watersheds had slightly higher TSS concentrations, but the instream sedimentation was over five times higher in streams associated with recently logged watersheds. Instream woody debris was about 50% higher in streams in recently logged watersheds than in watersheds with no visible signs of timber harvest. Stream median NO_3 concentrations were three times higher in previously logged or unlogged watersheds compared to recently logged watersheds. Stream median TP concentrations were comparable, but slightly higher in previously harvested watersheds. It appears there might be physical habitat effects of timber harvesting apparent at a regional scale, but the sample size is limited. With the exception of woody debris, stream effects from timber harvesting in first order streams are comparable or less than stream effects associated with mixed land use practices in Highland watersheds.

In general, a regional signature of forest management practices on impaired stream quality is not apparent. In fact, stream quality associated with forest land use throughout the Highlands is "good" and might provide a reference for what is attainable in the region. About 1% to 2% of the Highland forested area is harvested each year. With stream effects associated with logging expected to return to within preharvest variance levels in 2 to 5 years (Binkley and Brown 1993), the likelihood of detecting stream effects of forest harvest at a regional scale is low. There might be stream effects of forest management practices at a regional scale, but the signature is either masked or subtle.

Table III

Comparison of first order stream median characteristics in recently logged watersheds with streams in past or unharvested watersheds.

Timber Harvest	N	Road Density (m/ha)	TSS (mg/L)[1]	% Fines (% Stream Bed)
Recent	7	16.1	4.5	11
Previous or unharvested	101	6.9	3.8	2

Timber Harvest	Woody Debris (#pieces / 100m)	NO_3 (mg/L)[2]	TP (mg/L)[3]	EPT (# genera)[4]
Recent	34	0.2	.006	11
Previous or unharvested	23	0.7	.008	12

[1] Total suspended solids (TSS)
[2] Nitrate-nitrogen (NO_3)
[3] Total phosphorus (TP)
[4] *Ephemeroptera-Plecoptera-Trichoptera* (EPT) aquatic insect index

4. Conclusions

Based on the literature review and the analysis of mid-Atlantic Highland streams data:

1) Short-term (i.e., 2 to 5 years) effects of forest management practices on stream quality can occur at the local scale.
2) The signature of cumulative effects from forest management practices at the regional scale is not apparent from the Mid-Atlantic Highland stream monitoring program.
3) In general, forested land use is associated with the good stream quality in the region, compared to other land use practices.
4) Forested land use, and associated best management practices, might provide a reference for attainable stream quality in the region.

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